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(54) **CONTROLLED SHUTDOWN OF AN ELECTRIC VEHICLE**

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B60L 11/18 (2006.01)

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USPC **701/22**; 180/65.1; 320/132

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USPC 701/22; 903/902; 180/65.1; 318/139, 318/434; 340/425.5; 320/132
See application file for complete search history.

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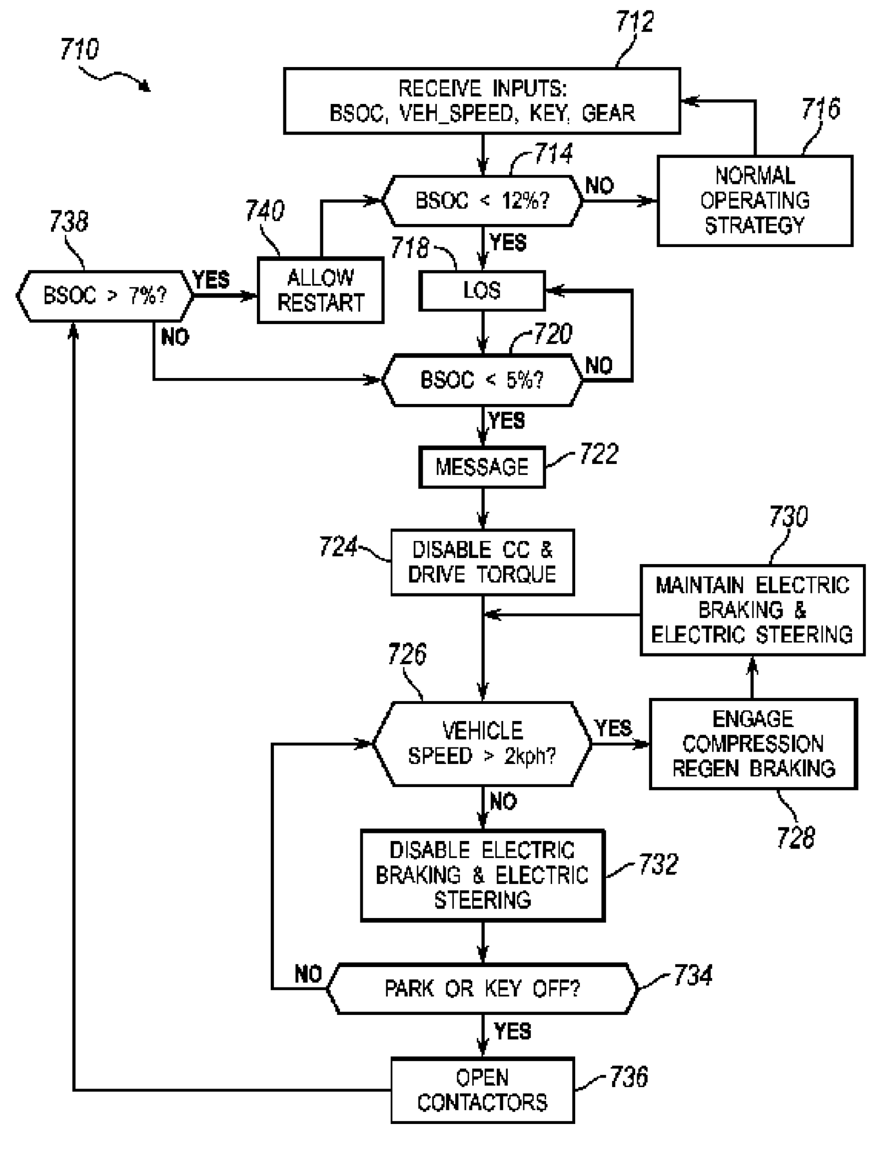
(57) **ABSTRACT**

A vehicle is provided with a motor that is configured to provide drive torque and to facilitate regenerative braking. The vehicle also includes a controller that is configured to receive input that is indicative of a vehicle speed and a battery state of charge (BSOC), and to disable the drive torque when the BSOC is less than a maximum discharge limit. The controller is also configured to activate regenerative braking when the BSOC is less than the maximum discharge limit and the vehicle speed is greater than a predetermined speed.

20 Claims, 5 Drawing Sheets



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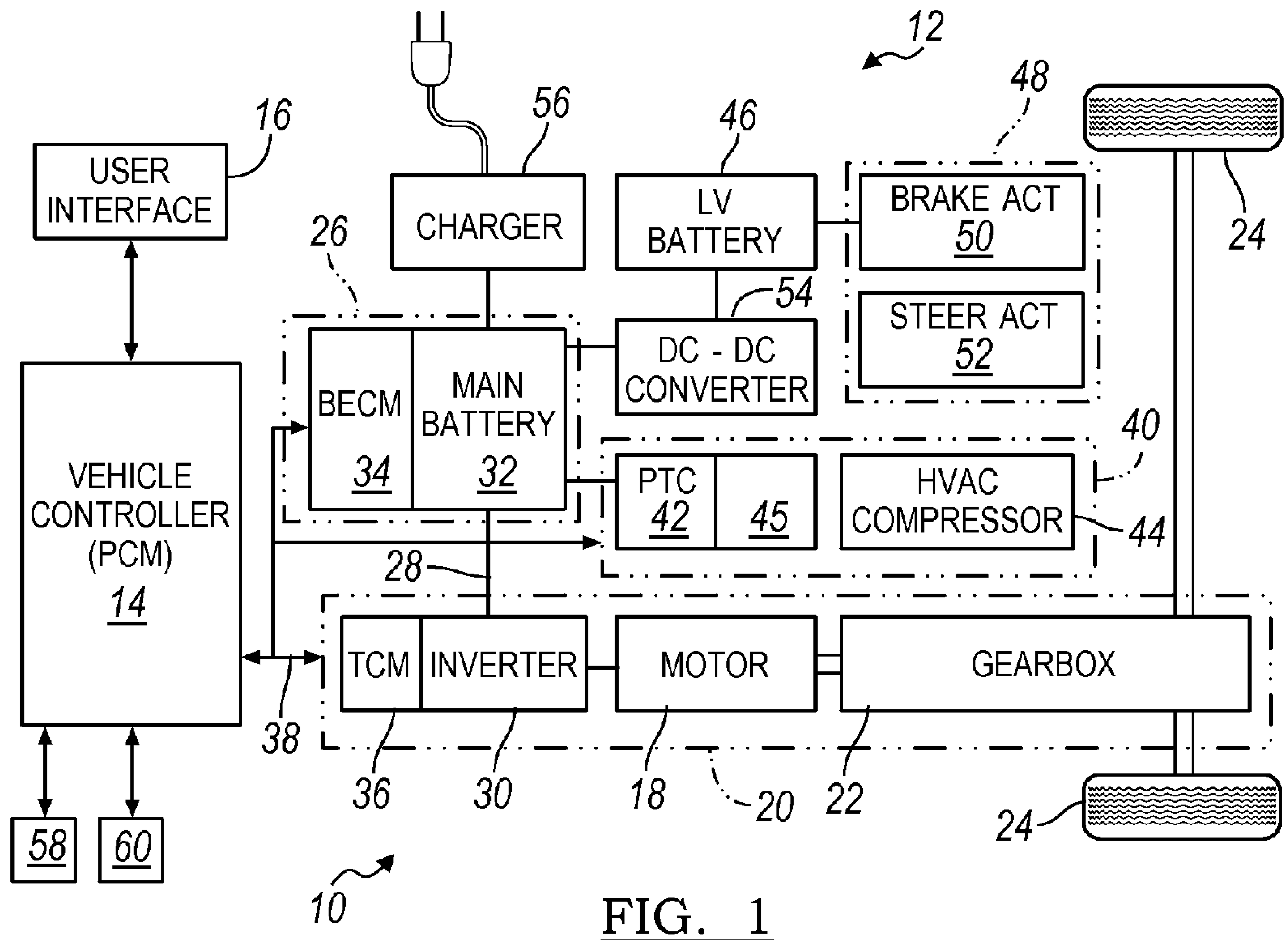
12
16
USER INTERFACE
56
CHARGER
46
LV BATTERY
48
BRAKE ACT
50
STEER ACT
52
24
26
BECM
34
MAIN BATTERY
32
54
DC - DC CONVERTER
40
PTC
42
45
HVAC COMPRESSOR
44
VEHICLE CONTROLLER (PCM)
14
28
TCM
INVERTER
MOTOR
GEARBOX
38
36
30
18
20
22
24
58
60
10

FIG. 1

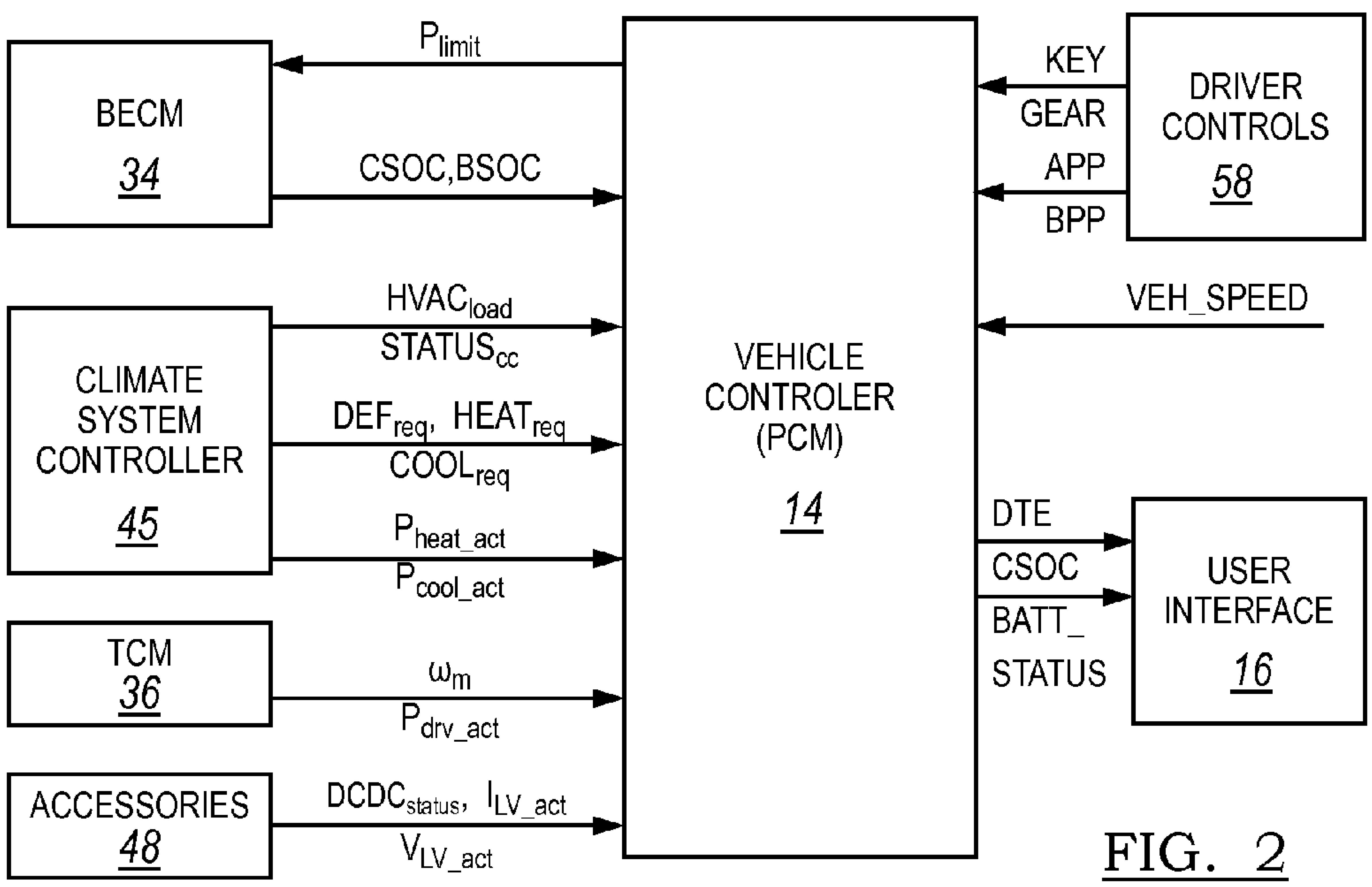
BECM
34
P_{limit}
CSOC,BSOC
CLIMATE SYSTEM CONTROLLER
45
$HVAC_{load}$
$STATUS_{cc}$
DEF_{req}, $HEAT_{req}$
$COOL_{req}$
P_{heat_act}
P_{cool_act}
TCM
36
ω_m
P_{drv_act}
ACCESSORIES
48
$DCDC_{status}$, I_{LV_act}
V_{LV_act}
VEHICLE CONTROLER (PCM)
14
KEY
GEAR
APP
BPP
DRIVER CONTROLS
58
VEH_SPEED
DTE
CSOC
BATT_
STATUS
USER INTERFACE
16

FIG. 2

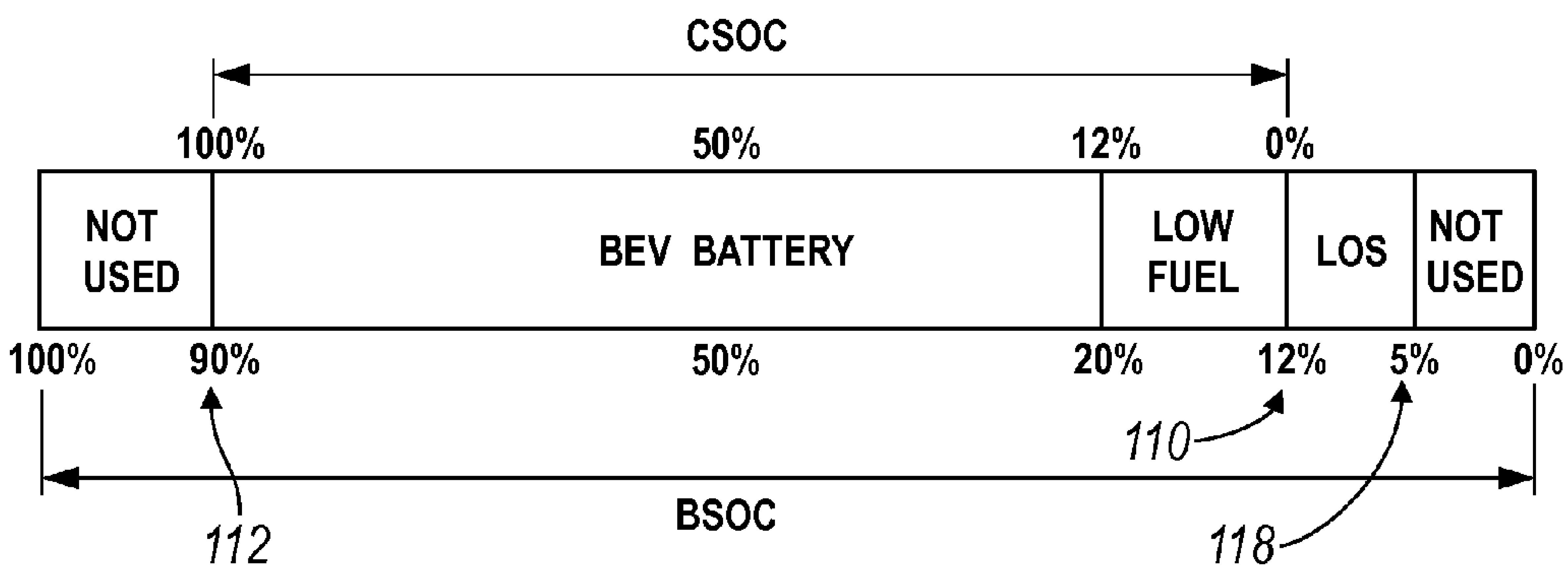
CSOC
100%
50%
12%
0%
NOT USED
BEV BATTERY
LOW FUEL
LOS
NOT USED
100%
90%
50%
20%
12%
5%
0%
110
112
BSOC
118

FIG. 3

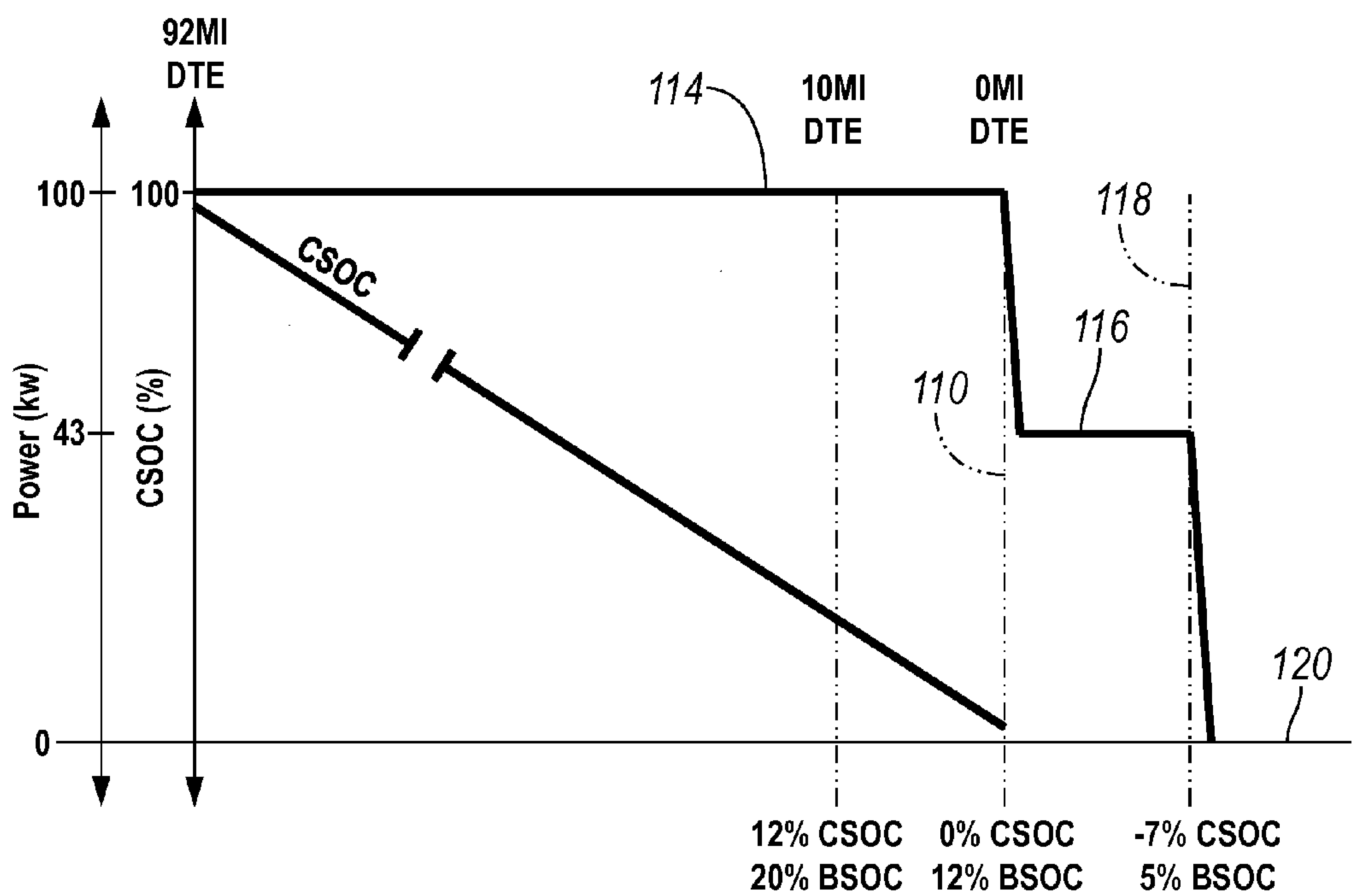
92MI DTE
114
10MI DTE
0MI DTE
118
100
100
CSOC
116
110
Power (kw)
CSOC (%)
43
120
0
12% CSOC 20% BSOC
0% CSOC 12% BSOC
-7% CSOC 5% BSOC

FIG. 4

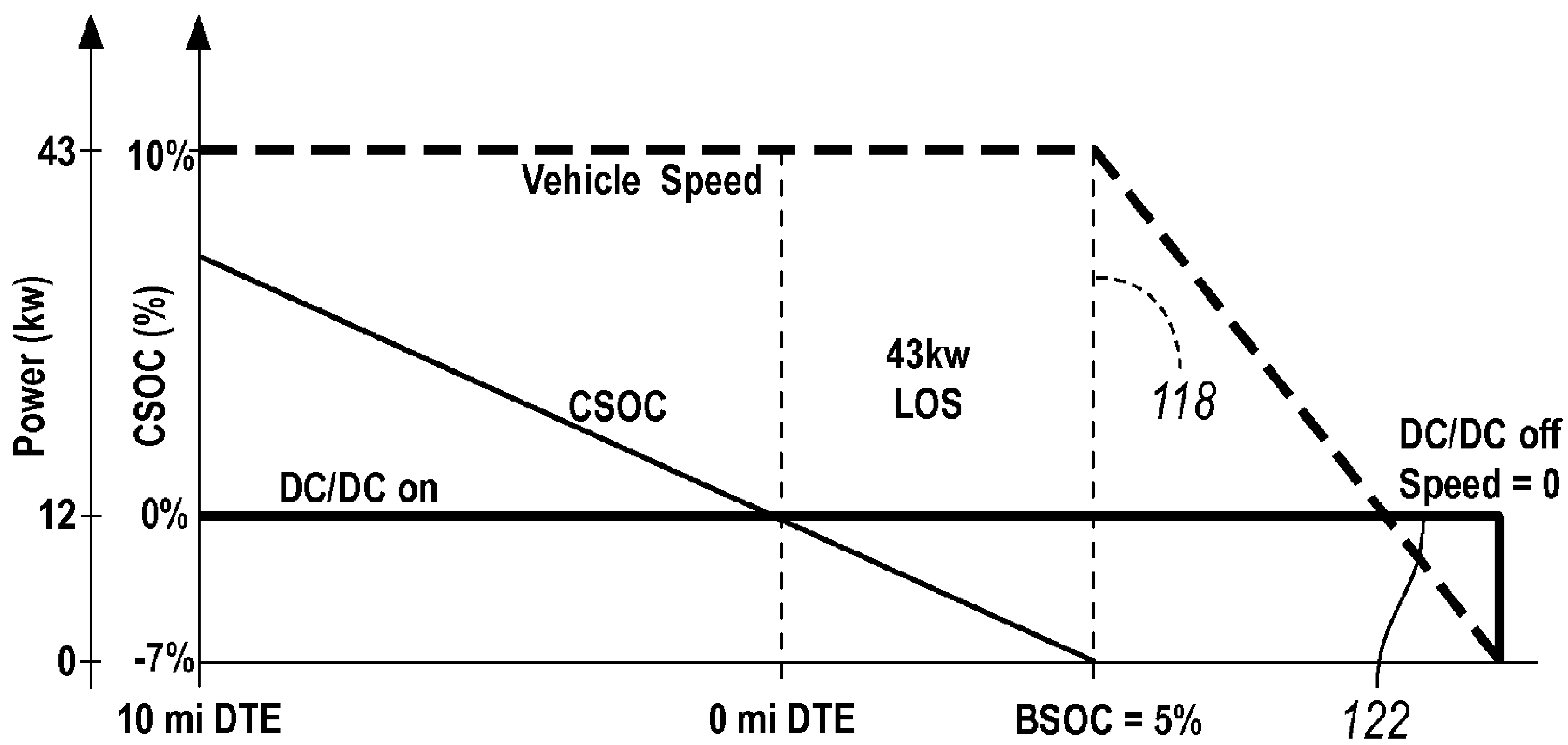
43
10%
Vehicle Speed
Power (kw)
CSOC (%)
43kw
LOS
CSOC
118
DC/DC off
Speed = 0
DC/DC on
12
0%
0
-7%
122
10 mi DTE
0 mi DTE
BSOC = 5%

FIG. 5

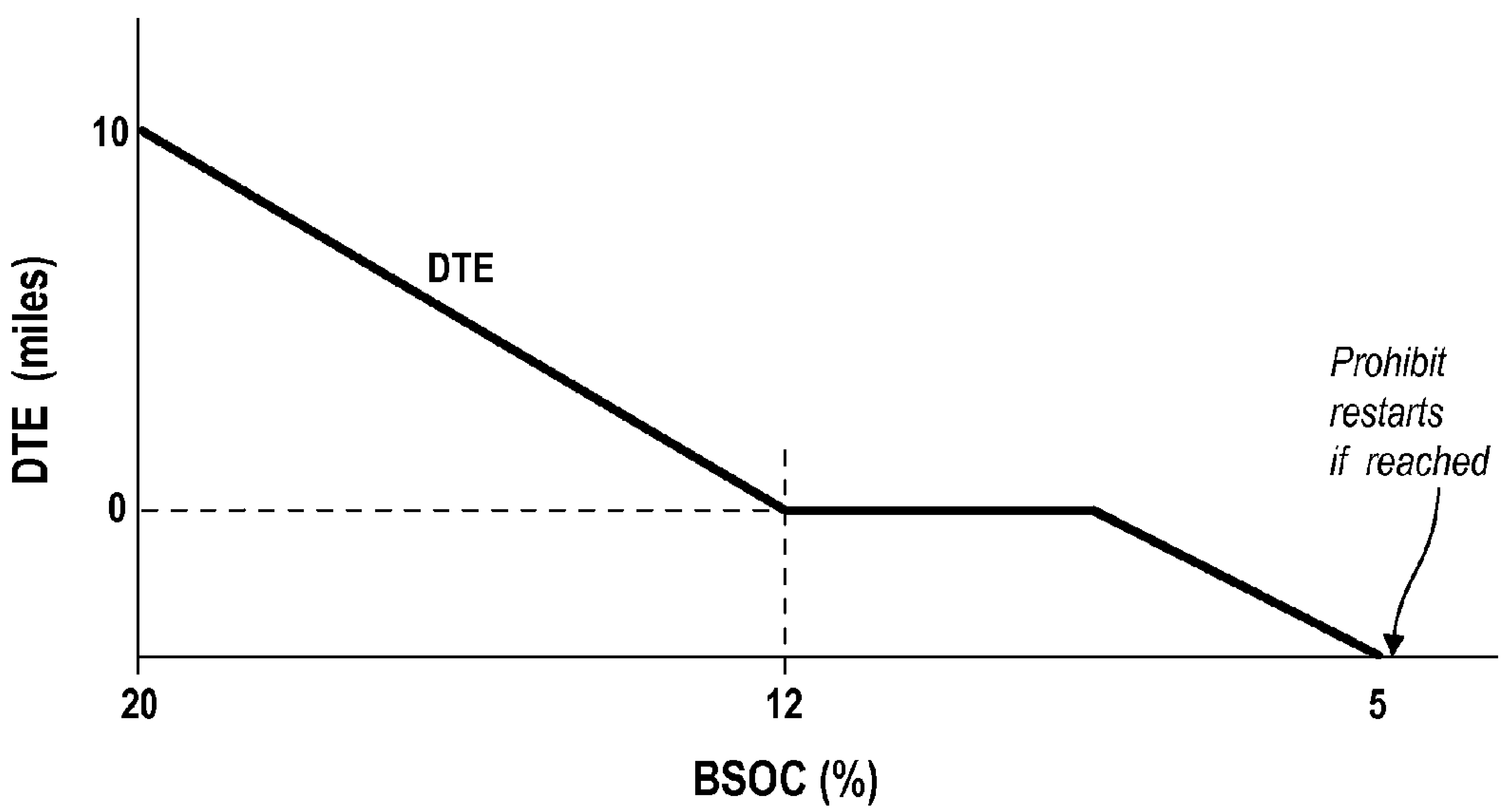
10
DTE
DTE (miles)
Prohibit
restarts
if reached
0
20
12
5
BSOC (%)

FIG. 6

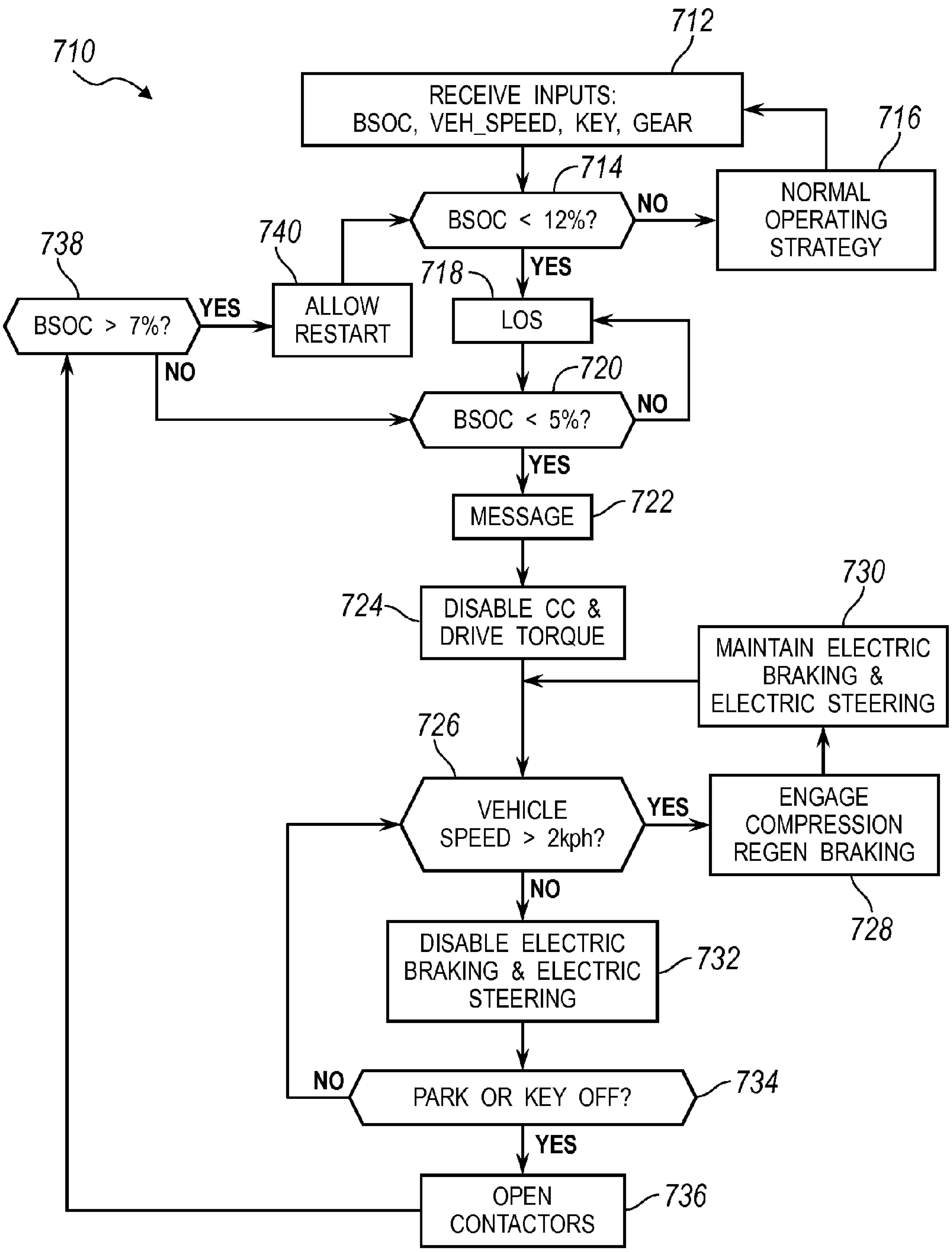
710
712
RECEIVE INPUTS:
BSOC, VEH_SPEED, KEY, GEAR
716
714
BSOC < 12%?
NO
NORMAL
OPERATING
STRATEGY
738
740
YES
718
BSOC > 7%?
YES
ALLOW
RESTART
LOS
NO
720
BSOC < 5%?
NO
YES
MESSAGE
722
724
DISABLE CC &
DRIVE TORQUE
730
MAINTAIN ELECTRIC
BRAKING &
ELECTRIC STEERING
726
VEHICLE
SPEED > 2kph?
YES
ENGAGE
COMPRESSION
REGEN BRAKING
NO
728
DISABLE ELECTRIC
BRAKING & ELECTRIC
STEERING
732
NO
PARK OR KEY OFF?
734
YES
OPEN
CONTACTORS
736

FIG. 7

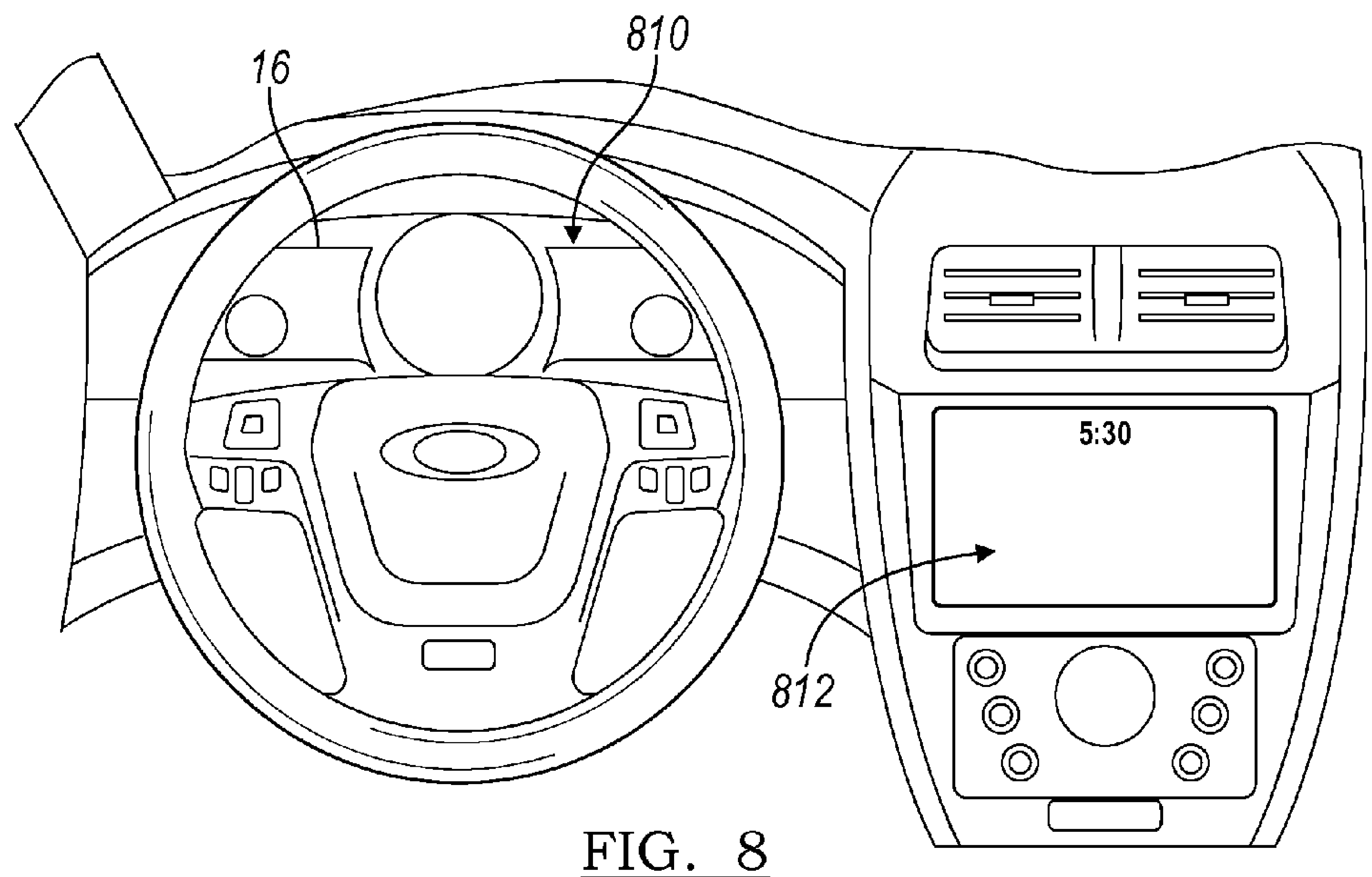
16
810
5:30
812

FIG. 8

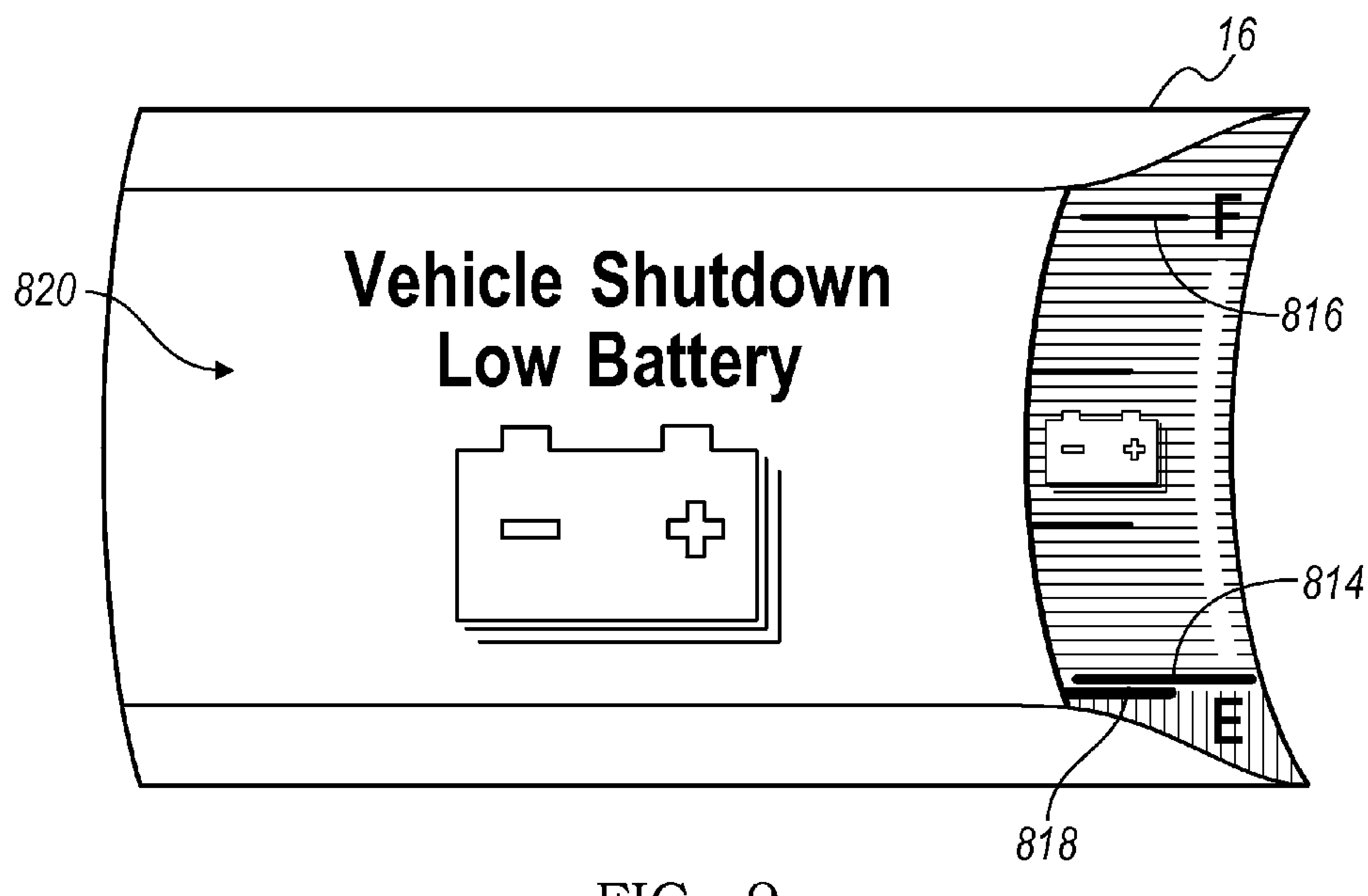
16
820
Vehicle Shutdown
Low Battery
F
816
814
E
818

FIG. 9

CONTROLLED SHUTDOWN OF AN ELECTRIC VEHICLE

TECHNICAL FIELD

One or more embodiments relate to a vehicle system and method for controlling shutdown of an electric vehicle at low battery power.

BACKGROUND

The term “electric vehicle” as used herein, includes vehicles having an electric motor for vehicle propulsion, such as battery electric vehicles (BEV), hybrid electric vehicles (HEV), and plug-in hybrid electric vehicles (PHEV). A BEV includes an electric motor, wherein the energy source for the motor is a battery that is re-chargeable from an external electric grid. In a BEV, the battery is the source of energy for vehicle propulsion. A HEV includes an internal combustion engine and an electric motor, wherein the energy source for the engine is fuel and the energy source for the motor is a battery. In a HEV, the engine is the main source of energy for vehicle propulsion with the battery providing supplemental energy for vehicle propulsion (the battery buffers fuel energy and recovers kinematic energy in electric form). A PHEV is like a HEV, but the PHEV has a larger capacity battery that is rechargeable from the external electric grid. In a PHEV, the battery is the main source of energy for vehicle propulsion until the battery depletes to a low energy level, at which time the PHEV operates like a HEV for vehicle propulsion.

The electric vehicle monitors the status of the battery using a number of measurements, including battery state of charge (BSOC). BSOC is a percentage that represents the amount of energy in the battery from 0% (empty) to 100% (full). Batteries may be damaged if they are overcharged or overly discharged. Therefore, many prior art electric vehicles maintain the battery within an operating range between a charging limit of approximately 80% BSOC and a discharge limit of approximately 20% BSOC.

SUMMARY

In one embodiment, a vehicle is provided with a motor that is configured to provide drive torque and to facilitate regenerative braking. The vehicle also includes a controller that is configured to receive input that is indicative of a vehicle speed and a battery state of charge (BSOC), and to disable the drive torque when the BSOC is less than a maximum discharge limit. The controller is also configured to activate regenerative braking when the BSOC is less than the maximum discharge limit and the vehicle speed is greater than a predetermined speed.

In another embodiment, a vehicle system is provided with a controller that is configured to receive input indicative of a vehicle speed and a battery state of charge (BSOC), and to disable drive torque when the BSOC is less than a maximum discharge limit. The controller is also configured to disable electric braking assistance and electric steering assistance when the BSOC is less than the maximum discharge limit and the vehicle speed is less than a predetermined speed.

In yet another embodiment, a method is provided for controlled shutdown of an electric vehicle. Input is received that is indicative of a vehicle speed and a battery state of charge (BSOC). Drive torque is disabled when the BSOC is less than a first discharge limit. Regenerative braking is activated when the BSOC is less than the first discharge limit and the vehicle speed is greater than the predetermined speed.

The disclosed vehicle system provides advantages by allowing the electric vehicle to operate below the discharge limit which extends the battery range. The vehicle system controls the shutdown of the electric vehicle once the BSOC is less than a maximum discharge limit by disabling vehicle propulsion systems and activating regenerative braking to provide energy for electric braking assistance and electric steering assistance.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of a vehicle system for controlling the shutdown of an electric vehicle according to one or more embodiments;

FIG. **2** is an enlarged schematic view of a portion of the vehicle system of FIG. **1**, illustrating vehicle communication;

FIG. **3** is a diagram illustrating battery state of charge (BSOC) limits and customer state of charge (CSOC) limits of the vehicle system of FIG. **1**;

FIG. **4** is a graph illustrating BSOC limits and battery power limits of the vehicle system of FIG. **1**;

FIG. **5** is a graph illustrating the battery power limits of FIG. **4** during regenerative braking;

FIG. **6** is another graph illustrating BSOC limits;

FIG. **7** is a flow chart illustrating a method for controlling the shutdown of an electric vehicle according to one or more embodiments;

FIG. **8** is a front perspective view of a user interface of the vehicle system of FIG. **1**; and

FIG. **9** is an enlarged view of the user interface of FIG. **8** according to one or more embodiments.

DETAILED DESCRIPTION

As required, detailed embodiments of the present invention are disclosed herein; however, it is to be understood that the disclosed embodiments are merely exemplary of the invention that may be embodied in various and alternative forms. The figures are not necessarily to scale; some features may be exaggerated or minimized to show details of particular components. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a representative basis for teaching one skilled in the art to variously employ the present invention.

With reference to FIG. **1**, a vehicle system for controlling the shutdown of an electric vehicle is illustrated in accordance with one or more embodiments and is generally referenced by numeral **10**. The vehicle system **10** is depicted within a vehicle **12**. The vehicle system **10** includes a vehicle controller **14** and a user interface **16** that are in communication with each other. The vehicle controller **14** receives input signals and controls the shutdown of the vehicle **12**. The vehicle controller **14** transmits this information to the user interface **16**, which in turn conveys the information to the driver in real time. The driver may use this information as a warning, and prepares for shutdown by maneuvering the vehicle **12** to a suitable parking location.

The illustrated embodiment depicts the vehicle **12** as a battery electric vehicle (BEV), which is an all-electric vehicle propelled by an electric motor **18** without assistance from an internal combustion engine (not shown). The motor **18** receives electrical power and provides drive torque for vehicle propulsion. The motor **18** also functions as a generator for converting mechanical power into electrical power through regenerative braking. The vehicle **12** has a powertrain **20** that includes the motor **18** and a gearbox **22**. The gearbox **22** adjusts the drive torque and speed of the motor **18** by a predetermined gear ratio. A pair of half-shafts extend in opposing directions from the gearbox **22** to a pair of driven wheels **24**.

Although illustrated and described in the context of a BEV **12**, it is understood that embodiments of the present application may be implemented on other types of electric vehicles, such as those powered by an internal combustion engine in addition to one or more electric machines (e.g., hybrid electric vehicles (HEVs), full hybrid electric vehicles (FHEVs) and plug-in electric vehicles (PHEVs), etc.).

The vehicle **12** includes an energy storage system **26** for storing and controlling electrical energy. A high voltage bus **28** electrically connects the motor **18** to the energy storage system **26** through an inverter **30**. The energy storage system **26** includes a main battery **32** and a battery energy control module (BECM) **34** according to one or more embodiments. The main battery **32** is a high voltage battery that is capable of outputting electrical power to operate the motor **18**. The main battery **32** also receives electrical power from the motor **18**, when the motor **18** is operating as a generator during regenerative braking. The inverter **30** converts the direct current (DC) power supplied by the main battery **32** to alternating current (AC) power for operating the motor **18**. The inverter **30** also converts alternating current (AC) provided by the motor **18**, when acting as a generator, to DC for charging the main battery **32**. The main battery **32** is a battery pack made up of several battery modules (not shown), where each battery module contains a plurality of battery cells (not shown). The BECM **34** acts as a controller for the main battery **32**. The BECM **34** also includes an electronic monitoring system that manages temperature and state of charge of each of the battery cells. Other embodiments of the vehicle **12** contemplate different types of energy storage systems, such as capacitors and fuel cells (not shown).

The powertrain **20** includes a traction control module (TCM) **36** for controlling the motor **18** and the inverter **30**. The TCM **36** monitors, among other things, the position, speed, and power consumption of the motor **18** and provides output signals corresponding to this information to other vehicle systems. The TCM **36** and the inverter **30** convert the direct current (DC) voltage supply by the main battery **32** into alternating current (AC) signals that are used to control the motor **18**.

The vehicle controller **14** communicates with other vehicle systems and controllers for coordinating their function. Although it is shown as a single controller, the vehicle controller **14** may include multiple controllers that may be used to control multiple vehicle systems according to an overall vehicle system control (VSC) logic, or software. For example, the vehicle controller **14** may be a powertrain control module (PCM) having a portion of the VSC software embedded therein. The vehicle controller **14** generally includes any number of microprocessors, ASICs, ICs, memory (e.g., FLASH, ROM, RAM, EPROM and/or EEPROM) and software code to co-act with one another to perform a series of operations. The vehicle controller **14** also includes predetermined data, or "look up tables" that are based on calculations and test data and stored within the memory. The vehicle controller **14** communicates with other controllers (e.g., TCM **36**, BECM **34**) over a hardline vehicle connection **38** using a common bus protocol (e.g., CAN).

The user interface **16** communicates with the vehicle controller **14** for receiving information regarding the vehicle **12** and its surroundings, and conveys this information to the driver. The user interface **16** includes a number of interfaces, such as gauges, indicators, and displays (shown in FIG. **8**). The user interface **16** also includes a controller (not shown) for communicating with external devices, such as a computer or cellular phone in one or more embodiments. The vehicle controller **14** provides output to the user interface **16**, such as a status of the motor **18** or battery **32**, which is conveyed visually to the driver.

The vehicle **12** includes a climate control system **40** for heating and cooling various vehicle components and a passenger compartment (not shown). The climate control system **40** includes a high voltage positive temperature coefficient (PTC) electric heater **42** and a high voltage electric HVAC compressor **44**, according to one or more embodiments. The PTC heater **42** and HVAC compressor **44** are used to heat and cool fluid, respectively, that circulates to the powertrain **20** and to the main battery **32**. Both the PTC heater **42** and the HVAC compressor **44** may draw electrical energy directly from the main battery **32**. The climate control system **40** includes a climate controller **45** for communicating with the vehicle controller **14** over the CAN bus **38**. The on/off status of the climate control system **40** is communicated to the vehicle controller **14**, and can be based on, for example, the status of an operator actuated switch, or the automatic control of the climate control system **40** based on related functions, such as window defrost. In other embodiments, the climate control system **40** is configured for heating and cooling air (e.g., existing vehicle cabin air) rather than fluid, and circulating the air through the battery **32** and/or powertrain **20**.

The vehicle **12** includes a secondary low voltage (LV) battery **46**, such as a 12-volt battery, according to one embodiment. The secondary battery **46** may be used to power various vehicle accessories **48** such as an electric braking actuator **50** and an electric steering actuator **52**.

A DC-to-DC converter **54** is electrically connected between the main battery **32** and the LV battery **46**. The DC-to-DC converter **54** adjusts, or "steps down" the voltage level to allow the main battery **32** to charge the LV battery **46**. A low voltage bus electrically connects the DC-to-DC converter **54** to the LV battery **46** and the accessories **48**.

The vehicle **12** includes an AC charger **56** for charging the main battery **32**. An electrical connector connects the AC charger **56** to an external power supply (not shown) for receiving AC power. The AC charger **56** includes power electronics used to invert, or "rectify" the AC power received from the external power supply to DC power for charging the main battery **32**. The AC charger **56** is configured to accommodate one or more conventional voltage sources from the external power supply (e.g., 110 volt, 220 volt, etc.). The external power supply may include a device that harnesses renewable energy, such as a photovoltaic (PV) solar panel, or a wind turbine (not shown).

Also shown in FIG. **1** are simplified schematic representations of a driver controls system **58** and a navigation system **60**. The driver controls system **58** includes acceleration, braking, steering and gear selection (shifting) systems (all generally referenced by numeral **58**).

The acceleration system includes an accelerator pedal having one or more sensors, which provides pedal position information that corresponds to a driver request for drive torque.

The braking system includes a brake pedal, a booster, a master cylinder, as well as a mechanical connection to the vehicle wheels, such as the primary driven wheels **24**, to effect friction braking. The braking system also includes the electric braking actuator **50** which assists friction braking by adjusting internal pressure within the booster or master cylinder. If electrical power to the electric braking actuator **50** were disrupted, then the mechanical connections within the braking system would engage and allow for mechanical (unassisted) friction braking. The braking system also includes position sensors, pressure sensors, or some combination thereof for providing information such brake pedal position that corresponds to a driver request for brake torque.

The braking system also includes a brake controller (not shown) that communicates with the vehicle controller **14** to coordinate regenerative braking and friction braking. The brake controller provides an input signal to the vehicle controller **14** that corresponds to a total brake torque value. The total brake torque value is based on the accelerator pedal position and the brake pedal position. The vehicle controller **14** then compares the total brake torque value to other information to determine a regenerative braking torque value and a friction braking torque value, where the sum of the regenerative braking torque value and the friction braking torque value is approximately equal to the total brake torque value. The vehicle controller **14** provides the regenerative braking torque value to the TCM **36**, which in turn controls the motor **18** to provide regenerative braking. The vehicle controller also provides the friction braking torque value to the brake controller, which in turn controls the electric braking actuator **50** to provide friction braking.

In one or more embodiments, the braking system is configured to provide compression braking of the vehicle. Compression braking represents the frictional losses within an engine of a conventional vehicle, when a driver releases the accelerator pedal. Similarly, the braking system provides a total brake torque value when the accelerator pedal is released, even if the brake pedal is not depressed. The vehicle controller **14** then compares the total brake torque value to other information to determine a regenerative braking torque value and a friction braking torque value.

The vehicle **12** utilizes regenerative braking as the primary braking source, and supplements with friction braking when there is insufficient available regenerative braking torque to satisfy the total brake torque requested by the driver. Regenerative braking recharges the main battery **32** and recovers much of the energy that would otherwise be lost as heat during friction braking. Therefore regenerative braking improves the overall efficiency or fuel economy of the vehicle as compared to vehicles that are only configured for friction braking.

The steering system includes the electric steering actuator **52** which assists mechanical steering. If electrical power to the electric steering actuator **52** were disrupted, then the mechanical connections within the steering system would engage and allow for mechanical (unassisted) steering.

The gear selection system includes a shifter for manually selecting a gear setting of the gearbox **22**. The gear selection system may include a shift position sensor for providing shifter selection information (e.g., PRNDL) to the vehicle controller **14**.

The navigation system **60** may include a navigation display, a global positioning system (GPS) unit, a navigation controller and inputs (all not shown) for receiving destination information or other data from a driver. These components may be unique to the navigation system **60** or shared with other systems. The navigation system **60** may also communicate distance and/or location information associated with the vehicle **12**, its target destinations, or other relevant GPS waypoints.

With reference to FIGS. **1** and **2**, the vehicle controller **14** receives input that is indicative of current operating conditions of vehicle systems, and provides output to coordinate their function. Each input may be a signal transmitted directly between the vehicle controller **14** and the corresponding vehicle system, or indirectly as input data over the CAN bus **38**.

The BECM **34** provides input (BSOC, CSOC) to the vehicle controller **14** that represents the energy level of the main battery **32**. The BECM **34** monitors battery conditions such as battery voltage, current, temperature and state of charge measured values. The BECM **34** also compares current battery conditions to historic data to evaluate battery life ("aging"), change in capacity over time, faults, and any predetermined limits. The BSOC input represents the battery state of charge, which is the amount of electric energy of the main battery **32** as a percentage from 0% (empty) to 100% (full). The CSOC input represents the customer state of charge, which is the amount of "available" electric energy of the main battery **32** as a percentage. The relationship between BSOC and CSOC is described in detail below with respect to FIG. **3**.

The vehicle controller **14** provides input (P_{limit}) to the BECM **34** that represents an allowable battery power limit. During low BSOC conditions the vehicle controller **14** may reduce the allowable battery power limit to conserve battery power and control vehicle shutdown.

The climate controller **45** provides input ($HVAC_{load}$, $STATUS_{cc}$, $HEAT_{req}$, $COOL_{req}$) to the vehicle controller **14** that represent vehicle temperature conditions and driver thermal requests. The $HVAC_{load}$ input represents the electrical load of the climate control system **40** based on temperature conditions inside the vehicle **12**. The $HEAT_{req}$ input represents a driver request for heating, and the $COOL_{req}$ input represents a driver request for cooling. The $STATUS_{cc}$ input represents an on/off status of the climate control system **40**. The $STATUS_{cc}$, $HEAT_{req}$ and $COOL_{req}$ inputs are each based on a position of an operator actuated switch, knob or dial, which are collectively referred to as thermal controls and illustrated in FIG. **8**.

The climate control system **40** also includes a defrost feature where both the PTC heater **42** and HVAC compressor **44** are used to collectively melt ice and remove humidity from a front or rear window (not shown) of the vehicle **12**. In one or more embodiments, the climate controller **45** also provides an input (DEF_{req}) to the vehicle controller **14** that represents a driver request for defrost.

The vehicle controller **14** receives input (ω_m,P_{drv_act}) that is indicative of motor **18** conditions. The ω_m input represents the output speed of the motor **18**, and the P_{drv_act} input represents the actual electrical power provided to the motor **18** to generate drive torque for propelling the vehicle **12**.

The vehicle controller receives input (I_{LV_act}, V_{LV_act}) that represents the actual power usage of the accessories **48**. The vehicle **12** includes sensors (not shown) that measure the actual voltage and current that is provided by the main battery **32** to the LV battery **46**. These sensors provide the I_{LV_act} and V_{LV_act} inputs, which represent the actual current and the actual voltage provided to the LV battery **46**, respectively. In other embodiments, the vehicle controller **14** receives an input signal corresponding to the actual power (not shown) that is provided to the LV battery **46**. The vehicle controller also receives input ($DCDC_{status}$) that represents the status of the DC-DC converter **54**. The $DCDC_{status}$ input includes information regarding which accessories **48** are enabled. For example, in one or more embodiments, the vehicle system **10** may disable certain accessories **48**, or all accessories **48** by disconnecting electrical power to the DC-DC converter **54**.

The vehicle controller **14** receives input (KEY, GEAR, APP, BPP) from the driver controls **58** that represents the current position of a number of vehicle systems. The KEY input represents the position of the key (e.g., off, run, accessories). The GEAR input represents the gear position or selection (e.g., PRNDL). The APP input represents the accelerator pedal position. The BPP input represents the brake pedal position. The vehicle controller **14** also receives an input (VEH_SPEED) that represents the vehicle speed.

The vehicle controller **14** evaluates the input and provides output (CSOC, DTE, BAT_STATUS) to the user interface **16** that represents battery information such as CSOC and an estimated vehicle travel range, or "distance to empty" (DTE). The user interface **16** may display a message, such as a vehicle shutdown message (FIG. **9**) in response to the BAT_STATUS.

FIG. **3** is a diagram illustrating the relationship between battery state of charge (BSOC) and customer state of charge (CSOC). BSOC represents the electric energy of the main battery **32** as a percentage from 0% (empty) to 100% (full). Generally, batteries may be damaged if they are overcharged or overly discharged. Therefore, the main battery **32** is maintained within a reduced operating range during normal operating conditions. In one or more embodiments the reduced operating range is between 12% and 90% BSOC. The 12% BSOC value corresponds to a discharge limit and is referenced by numeral **110**. The 90% BSOC value corresponds to a charging limit and is referenced by numeral **112**. This battery energy level information is conveyed to the driver visually by the user interface (FIG. **9**). The driver uses this energy level information much like a fuel gage on a conventional vehicle. However, this reduced operation range may confuse a driver. Therefore, the vehicle system **10** calculates a customer state of charge (CSOC) which corresponds to the operating range of the BSOC. As shown in FIG. **3**, a CSOC value of 0% corresponds to the discharge limit **110** (12% BSOC) and a CSOC value of 100% corresponds to the charging limit **112** (90% BSOC).

Referring to FIGS. **3** and **4**, the battery **32** may be damaged if operated below the discharge limit **110** at high battery power levels. However, the battery **32** may operate below the discharge limit **110** at a reduced battery power level for a short distance (e.g., five to seven miles) without damaging the battery **32**. To extend the overall vehicle travel range, the vehicle system **10** initiates a limited operating strategy (LOS) once the BSOC reaches the discharge limit **110**. During LOS, the vehicle system **10** limits battery power from a full power limit (approximately 100 KW), which is referenced by numeral **114**, to an intermediate power limit (approximately 43 KW), which is referenced by numeral **116**. The vehicle system **10** reduces the battery power limit from full power limit **114** to intermediate power limit **116** at a ramp rate of approximately 5 KW/s. During LOS, the vehicle system **10** selectively reduces, or "sheds", electrical power usage to extend battery life and travel range without damaging the battery **32**, so that the driver can maneuver the vehicle to the nearest charging station.

A maximum discharge limit is referenced by numeral **118**. The battery **32** may be damaged if operated below the maximum discharge limit **118**. Therefore the vehicle system **10** initiates a controlled shutdown of the vehicle **12** when the BSOC is less than the maximum discharge limit **118**. The maximum discharge limit is between 6% and 3% BSOC, according to one or more embodiment. The maximum discharge limit is 5% BSOC in the illustrated embodiment. The vehicle system **10** reduces the battery power limit from the intermediate power limit **116** to shutdown (e.g., 0 KW), which is referenced by numeral **120**, at a ramp rate of approximately 5 KW/s.

With reference to FIG. **5**, the vehicle system **10** will activate regenerative braking at the maximum discharge limit **118**, according to one or more embodiments. During a controlled shutdown of the vehicle **12**, the vehicle system **10** reduces the battery power limit from the intermediate power limit **116** to shutdown **120** (e.g., 0 KW). However, during this shutdown period the vehicle system **10** activates regenerative braking, regardless of actual accelerator pedal position, by controlling the motor **18** to generate energy while decelerating (braking) the vehicle **12**. The vehicle system **10** provides the energy supplied by the regenerative braking to the DC-DC converter **54** for use by the electric braking actuator **50** and the electric steering actuator **52**. As illustrated by point **122** in FIG. **5**, this energy from regenerative braking extends the functionally of the electric braking actuator **50** and the electric steering actuator **52** while the vehicle **12** is moving, even if the battery power limit has already been reduced to a lower level.

Referring to FIG. **6**, the vehicle system **10** prohibits restarting the vehicle **12** after shutdown, according to one or more embodiments. Users of electrical systems (e.g., cellphones, laptop computers, etc.) often try to restart the electrical system after a forced system shutdown due to low battery energy. Such restarts may damage a battery. To avoid a similar situation on the vehicle **12**, the vehicle system prohibits a restart of the vehicle **12** until the BSOC is above a restart limit. The restart limit is between 12% and 6% BSOC according to one or more embodiments. The restart limit is 7% BSOC according to the illustrated embodiment. The difference between the restart limit (7% BSOC) and the maximum discharge limit (5% BSOC) allows for some hysteresis or variation in the BSOC calculation.

With reference to FIG. **7** a method for controlling the shutdown of the electric vehicle **12** of FIG. **1** is illustrated according to one or more embodiments and generally referenced by numeral **710**. The method **710** is implemented using software code contained within the vehicle controller **14** according to one or more embodiments.

In operation **712** the vehicle controller **14** receives input including the battery state of charge (BSOC), the vehicle speed (VEH_SPEED), the key position (KEY) and the gear selection (GEAR). In operation **714** the BSOC value is compared to the discharge limit (12% BSOC). If the BSOC value is greater than the discharge limit, then the vehicle controller **14** proceeds to operation **716** and applies a normal battery operating strategy. For example the battery power may be limited to approximately 100 kW at operation **716**. If the determination at operation **714** is positive, the vehicle controller **14** proceeds to operation **718** and applies a limited operating strategy (LOS). For example the battery power may be limited to approximately 43 kW at operation **718**.

In operation **720** the BSOC value is compared to the maximum discharge limit (5% BSOC). If the BSOC value is greater than the maximum discharge limit, then the vehicle controller **14** returns to operation **718** and applies the LOS. If the determination at operation **720** is positive, the vehicle controller **14** proceeds to operation **722** and initiates a vehicle shutdown strategy.

In operation **722** the vehicle controller **14** provides a battery status warning to the interface **16**, which is conveyed to the driver (as shown in FIG. **9**). In operation **724**, the vehicle controller **14** disables the climate control system **40** and the motor drive torque by reducing the battery power limit to zero KW.

In operation **726** the vehicle controller **14** compares the vehicle speed (VEH_SPEED) to a predetermined speed value. The predetermined speed value is between 5 and 0 kph according to one or more embodiments. The predetermined speed value is 2 kph in the illustrated embodiment. If the vehicle speed is greater than the predetermined speed value, then the vehicle controller proceeds to operation **728** and activates compression braking and/or regenerative braking. The energy generated by operation **728** is utilized to maintain the electric braking assistance and the electric steering assistance in operation **730**. If the determination at operation **726** is negative, then the electric braking assistance and the electric steering assistance are disabled at operation **732**.

In operation **734** the vehicle controller **14** analyzes the gear selection signal (GEAR) and the key position signal (KEY). If GEAR indicates that the vehicle **12** is in "park", or KEY indicates that the key is "off", then the vehicle controller **14** proceeds to operation **736** and opens electrical contactors within the battery **32**. By opening the electrical contactors the battery **32** is electrically disconnected from other vehicle components and subsystems, except for the AC charger **56**. If the determination at operation **734** is negative, the vehicle controller **14** returns to operation **726**.

In operation **738** the vehicle controller **14** analyzes the BSOC value to determine if the battery **32** has been recharged. If the BSOC value is greater than 7% BSOC, the vehicle controller proceeds to operation **740** and allows the driver to restart the vehicle. Then the vehicle controller returns to operation **714**. If the determination at operation **738** is negative, the vehicle controller **14** returns to operation **720**.

With reference to FIG. **8**, the user interface **16** is located within an instrument cluster **810** according to one or more embodiments. In other embodiments, the user interface may be located in a central portion of a dashboard **812** ("centerstack"). The user interface **16** may be a liquid crystal display (LCD), a plasma display, an organic light emitting display (OLED), or any other suitable display. The user interface **16** may include a touch screen or one or more buttons (not shown), including hard keys or soft keys, located adjacent the user interface **16** for effectuating driver input.

With reference to FIG. **9**, the user interface **16** conveys information, such as the customer state of charge CSOC. In the illustrated embodiment, the CSOC is conveyed pictorially as a gage where the discharge limit (0% CSOC) is represented by the letter "E" for "Empty" and by a horizontal line, referenced by numeral **814**. The charging limit (100% CSOC) is represented by the letter "F" for "Full" and by a horizontal line referenced by numeral **816**. The present energy level of the battery **32** in the illustrated embodiment is below the maximum discharge limit (5% BSOC, −7% CSOC) and is represented by horizontal line and referenced by numeral **818**, which is below the discharge limit **814**. As mentioned above with respect to FIG. **7**, the vehicle controller **14** provides a warning message to the interface **16** when the battery **32** reaches a BSOC that is less than the maximum discharge limit (5% BSOC). This warning message may be conveyed to the driver both pictorially and using text as generally referenced by numeral **820**.

As such the vehicle system **10** provides advantages by allowing the electric vehicle **12** to operate below the discharge limit which extends the battery range. The vehicle system **10** controls the shutdown of the electric vehicle **12** once the BSOC is less than a maximum discharge limit by disabling vehicle propulsion systems and activating regenerative braking to provide energy for electric braking assistance and electric steering assistance features

While embodiments are described above, it is not intended that these embodiments describe all possible forms of the invention. Rather, the words used in the specification are words of description rather than limitation, and it is understood that various changes may be made without departing from the spirit and scope of the invention. Additionally, the features of various implementing embodiments may be combined to form further embodiments of the invention.

What is claimed is:

1. A vehicle comprising:

a motor configured to provide drive torque and to facilitate regenerative braking; and

a controller configured to:

receive input indicative of a vehicle speed and a battery state of charge (BSOC),

disable the drive torque when the BSOC is less than a maximum discharge limit, wherein the maximum discharge limit is between 6% and 3% BSOC, and

activate regenerative braking only when the BSOC is less than the maximum discharge limit and the vehicle speed is greater than a predetermined speed.

2. The vehicle of claim **1** further comprising:

an electric braking actuator for assisting a friction braking system; and

an electric steering actuator for assisting a steering system;

wherein the controller is further configured to disable the electric braking actuator and the electric steering actuator when the BSOC is less than the maximum discharge limit and the vehicle speed is less than the predetermined speed.

3. The vehicle of claim **2** further comprising:

a climate control system; and

a battery for providing electrical energy to the motor, the climate control system, the electric braking actuator and the electric steering actuator;

wherein the controller is further configured to disable the climate control system when the BSOC is less than the maximum discharge limit.

4. The vehicle of claim **1** wherein the predetermined speed is between 5 and 0 kph.

5. The vehicle of claim **1** further comprising:

an interface communicating with the controller and configured to display a warning message when the BSOC is less than the maximum discharge limit.

6. The vehicle of claim **1** wherein the controller is further configured to:

limit the drive torque when the BSOC is less than a discharge limit and greater than the maximum discharge limit.

7. The vehicle of claim **6** wherein the discharge limit is approximately 12% BSOC.

8. A vehicle system comprising:

a controller configured to:

receive input indicative of a vehicle speed and a battery state of charge (BSOC),

disable drive torque responsive to the BSOC decreasing below a maximum discharge limit of between 6% and 3% BSOC, and

disable electric braking assistance and electric steering assistance when the BSOC is less than the maximum discharge limit and the vehicle speed is less than a predetermined speed.

9. The vehicle system of claim **8** wherein the controller is further configured to disable drive torque by decreasing an available battery power limit to 0 KW at a controlled ramp rate.

10. The vehicle system of claim **8** wherein the controller is further configured to:

activate regenerative braking when the BSOC is less than the maximum discharge limit and the vehicle speed is greater than the predetermined speed.

11. The vehicle system of claim **8** wherein the controller is further configured to:

disable a climate control system when the BSOC is less than the maximum discharge limit.

12. The vehicle system of claim 8 further comprising:

an interface communicating with the controller and configured to display a vehicle shutdown message when the BSOC is less than the maximum discharge limit.

13. The vehicle system of claim 8 wherein the controller is further configured to:

receive input indicative of a gear selection and a key position; and

electrically disconnect a battery from a motor in response to at least one of a gear selection of park and a key position of off.

14. A vehicle system comprising:

a controller configured to:

receive input indicative of a vehicle speed, a key position and a battery state of charge (BSOC),

disable drive torque in response to the BSOC being less than a first discharge limit,

activate regenerative braking only in response to the BSOC being less than the first discharge limit and the vehicle speed being greater than a predetermined speed,

electrically disconnect a battery from a motor in response to a key position of off, and

upon electrically disconnecting the battery, electrically reconnect the battery to the motor in response to the BSOC increasing above a second discharge limit to allow vehicle restart, the second discharge limit being greater than the first discharge limit.

15. The vehicle system of claim 14 wherein the controller is further configured to:

supply energy generated during regenerative braking to an electric braking actuator for providing braking assistance.

16. The vehicle system of claim 14 wherein the controller is further configured to:

supply energy generated during regenerative braking to an electric steering actuator for providing steering assistance.

17. The vehicle system of claim 14 wherein the controller is further configured to:

disable an electric brake actuator and an electric steering actuator in response to the BSOC being less than the first discharge limit and the vehicle speed being less than a predetermined speed.

18. The vehicle system of claim 14 wherein the controller is further configured to:

disable a climate control system in response to the BSOC being less than the first discharge limit.

19. The vehicle system of claim 14 wherein the controller is further configured to:

display a vehicle shutdown message in response to the BSOC being less than the first discharge limit.

20. The vehicle system of claim 14 wherein the controller is further configured to:

receive input indicative of a gear selection; and

electrically disconnect a battery from at least one of a motor and a climate control system in response to a gear selection of park.

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